ESS 582

Economic Considerations in Landspreading Sewage Sludge

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February 1980

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In the past decade, the nation has increased its awareness of the finiteness of our natural resources and their ability to assimilate the by-products of our industrial society. Many of these by-products were discharged in the effluents from municipal wastewater treatment plants. Pollutants in effluents have been sharply curtailed over the past decade as a result of implementing provisions of the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500, 18 Oct. 1972). As treatment plants have improved the quality of effluents, a new problem has been created: how to dispose of the increased quantity of treated solids (i.e. sludge) removed from the effluent. In 1970, four million tons of sludge were produced, and it is projected that over 8 million tons will be produced in 1985 (Council for Agricultural Science and Technology).

The objectives of this report are to (a) summarize previous research comparing the costs of various sludge disposed methods, (b) outline alternative systems for one promising disposal method, landspreading, and (c) make economic comparisons of alternative landspreading systems.

Sludge Disposal Methods

Sludge is far from a uniform product. Its characteristics vary from community to community. These characteristics are determined, in part, by the wastewater treatment processes. Sludge can be stabilized by lime stabilization, anaerobic digestion, aerobic digestion, or thermal conditioning. It can be further treated by thickening processes or dewatering methods to increase the proportion of solids in the final product. Finally, it can be disposed of by either burning (incineration), composting, landfilling, or landspreading.

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Sludge treatment and disposal options are described in detail in numerous publications (e.g. U.S. Environmental Protection Agency, October 1978; U.S. Environmental Protection Agency, October 1975; and Research and Education Association). These options are only briefly described here.

Sewage sludge incineration has been practiced for several decades. Cheap energy and minimal or nonexistant air pollution control encouraged its adoption as a practical and inexpensive method of reducing sludge volume. Incineration typically is preceded by processes to reduce the water content of the sludge. For example, sludges might be thickened, digested, and dewatered, or they might be stabilized chemically and dewatered before entering the incineration process. Although the heat value of a dry ton of sludge is high, the water content of most sludges requires an auxiliary fuel source to maintain combustion. Of course, rising fuel costs are the major drawback to this system.

Due to rising fuel costs, partial pyrolysis has been demonstrated to be a means of combusting sludge without large amounts of supplemental fuel. The principle is to reduce the amount of air heated to combustion temperature which prevents wasting energy to heat excess air in the furnace. Pilot operations have shown advantages of slightly lower operating costs and reduced air emissions compared to traditional incineration processes.

Cocombustion is another method to reduce the fossil fuel requirements of incineration. Sewage sludge is combined with any number of materials and then burned. A potential advantage is that a waste material, such as municipal solid waste, can be disposed while providing an autogenous sludge feed (U.S. Environmental Protection Agency, October 1978). Besides handling both solid waste and sludge in an environmentally acceptable manner, the process produces heat, may provide benefits as an energy source, and may slightly reduce operating costs.

Composting is another sludge disposal option. Usually dewatered sludge is mixed with a bulking agent (e.g. wood chips) to reduce moisture content. Piles of the mixture are constructed and aerated for 21 to 30 days. Piles are dismantled and allowed to cure for another 30 days. The compost is then screened to recover the bulking agent and the stabilized sludge is landspread or landfilled. Composting may be a viable alternative for many locations, but the basic processes are still in the development and demonstration phase.

Lagooning involves dumping sludge into a large open pit. The liquid is decanted off, and the sludge is allowed to dry. When the lagoon is full, it is covered by a layer of earth, and another lagoon is started. Two potential problems are present. First, the lagoon floor may be permeable and permit leaching, and second, odors may produce adverse public reaction. But more importantly, lagooning must be viewed as only a temporary disposal method due to the land constraints facing most communities.

With landfilling, dewatered sludges are buried in a trench or area landfill. The sludge is periodically covered with a layer of soil to control odor. Sludges placed in area landfills may be mixed with soil in order to support equipment working on top of the landfill. Sludge may also be mixed with solid waste and codisposed in landfills. Sites must be selected which prevent pollution of surface or ground waters. In addition, odors must be controlled.

Landspreading, the focus of this report, utilizes sludge treated by aerobic or anaerobic digestion. Before landspreading, stabilized sludge may undergo dewatering to reduce its volume. Methods of handling and application are quite diverse. Tank trucks or tank wagons generally are used to haul liquid sludges with 1 to 7 percent solids. Truck spreaders are used for dewatered sludges with solids content of 15 to 50 percent. Irrigation of liquid sludge is possible. Also, rail or barge transportation systems could be used.

Another treatment method is land treatment of both effluents and sludges. It is based on the use of soil and its biological systems as a treatment process. Primary or secondary treatment processes may be followed by land treatment. The result is that up to 100 percent of BOD, suspended solids, nitrogen, and phosphorus can be removed from the wastewaters before final discharge into water bodies.

Economic Comparisons for Sludge Disposal Methods

A number of researchers have investigated the costs of alternative sludge disposal methods. Burd reviewed data available in the late 1960s and drew some generalizations about relative costs of alternative sludge disposal methods. Estimates were that capital and operating costs were $15 per dry ton for landspreading liquid sludge and $25 per dry ton for landspreading dewatered sludge. Landfilling dewatered sludge was estimated at $25 per dry ton, and incineration at $30 to $42 per dry ton. Due to a lack of data, Burd was unable to relate these costs to volume of sludge produced by the plant. A weakness of Burd's analysis was that no economic benefits were attributed to the plant nutrient value of landspread sludge.

Ewing and Dick compared the relative costs of the principle disposal methods in 1970. Their estimates showed landspreading liquid sludge costing $15 per dry ton, landspreading dewatered sludge $25 per dry ton, lagooning $18 per dry ton, and incineration $50 per dry ton. Again, no benefits were attributed to landspreading. However, landspreading and incineration costs were compared for a range of community sizes, and landspreading costs were approximately $40 per dry ton less than incineration costs over a wide range of community size.

More recent estimates by Shea and Stockton again found landspreading as the least expensive method of sludge disposal. Their estimates included the costs of thickening and digestion as well as costs for ultimate disposal (i.e. landfilling, landspreading, and incineration). Table 1 shows the relative advantage of landspreading over a range of treatment plant size.

Shea and Stockton's landspreading costs were based on the assumption that land was purchased for spreading sites. This assumption biased landspreading costs upward since most landspreading communities spread sludge on land owned by individuals. They pay no rent for the land nor do they pay any land ownership costs as Shea and Stockton's analysis assumed. Also, their analysis attributed no benefits to the plant nutrients provided by landspreading.

Colacicco et al. provided estimates of sludge disposal costs and a summary is shown in Table 2. Again, landspreading was shown to be an economically advantageous method of sludge disposal.

Land treatment of wastewater appears to be a promising treatment technology for small communities, for areas where water is in short supply, or for those communities where removal of nearly all pollutants from the effluent is required. Capital and operating costs may be lower than with conventional treatment and sludge disposal systems. Young and Carlson found that land treatment reduced costs compared to conventional treatment and sludge disposal systems. They projected savings of $0.40 per 1000 gallons of wastewater for the 0.5 MGD plant and $0.14 per 1000 gallons for the 10 MGD plant. Williams et al. compared land treatment and conventional treatment systems in a number of small Michigan communities. Land treatment systems had lower initial capital outlays and annual operating costs than did the conventional treatment systems. However, it is concluded in Young and Epp that acreage requirements for wastewater treatment suggest that land application is most applicable to smaller communities or for treatment of only part of the total wastewater from a large community.

Benefits of Landspreading Sludge

The primary benefit of sludge is its nutrient value. Nitrogent, phosphorus, and potassium concentrations average about 3.3, 2.4, and 0.3 percent, respectively, of dry sludge. These nutrients are required by most plants, and applications of commercial fertilizers are used with growing crops to supply sufficient quantities of these nutrients. Sludge can provide at least part of these nutrients. At the recommended sludge application rates (2 to 3 dry tons per acre, see Miller et al.), sludge supplies at least part of the nitrogen and frequently all of the phosphorus needed for growing crops.

There may be some benefits for sludge as a soil conditioner on cropland. Organic matter in the soil enhances soil texture, promotes aeration and increases moisture-holding capacity. All of these characteristics may lead to increased crop production. If soils have been "run down" to the point where organic matter content is low, then application of sludge could have a significant effect. If, on the other hand, the soil has been well-managed prior to sludge application, little effect may occur. Similarly, in years with good rainfall, the moisture retention effect may not be significant while in dry years it may be important. With this uncertainty relating to the value of sludge as a soil conditioner, one may either assume no difference or make some arbitrary adjustment to represent the effect over a period of years. Typically, sludge at recommended application rates provides such small benefits as a soil conditioner for cropland that it can be ignored.

Most sludges have many of the micronutrients that are needed by crops. However, some of the micronutrients in large quantities can be detrimental to the crop. The metal content of some sludges makes them unfit for use on land. Another problem with many sludges, especially dewatered sludges, is that they may have a high salt content. These salts are easily leachable, but can create problems when applied in large quantities in arid regions.

There is a large non-farm demand for good quality topsoil and soil conditioners that sludge products have helped fill. Sludge has been successfully used in reclaiming surface mines. Sludge has been used to renovate urban park land and has saved hundreds of thousands of dollars in topsoil costs. Sludge and sludge products have been found to compare successfully with potting mixes for nursery applications. Likewise, sludge-derived products have been sold to homeowners as soil conditioners.

The benefits depend on the use of the sludge, the soil characteristics, the nutrient content of the sludge, the application rate, and the price of other nutrient sources which sludge is replacing. For use on cropland, the potential value of sludge may total about $33 per dry ton as shown in Table 3.

To realize all the potential value of sludge, the recipient must restrict sludge application to relatively low rates. Application rates in excess of 2-3 tons per acre annually result in much of sludge nutrients being unused by the crop. These unused nutrients are either lost for crop growth, or their use by crops is delayed until later growing seasons. The appropriate sludge application rate for a particular site is governed largely by the type of crop being grown, the yield goal for that crop, the existing nutrient level of the soils at the spreading site, and the nutrient content of the sludge. Local agricultural experts need to be consulted to determine the nutrient needs of the crop. Treatment plant officials then should determine the amount of nutrients available in its sludge. Information about crop nutrient needs should be compared to the supply of nutrients in the sludge to determine the proper application rate. Supplemental application of commercial fertilizer likely would be required to meet any nutrient deficiencies.

Outline of Alternative Sludge Landspreading Technologies

Before landspreading, the stabilized sludge may undergo further dewatering treatment to reduce its volume. Sludge can be dewatered by chemicals, mechanical processes, heating, drying, or some combination of these four processes. Solids content before dewatering typically ranges from 1 to 7 percent, but after dewatering solids range between 15 and 50 percent.

Methods of handling and applying sludge during land application are quite diverse. The most typical method is the use of tank trucks or tank wagons to haul and spread sludge having 1 to 7 percent solids. These tank trucks or wagons may have high flotation tires for traversing soft ground and to minimize soil compaction problems. Attachments allow the liquid to be: (a) spread on the surface by gravity discharge; (b) spread on the surface to the side of the vehicle by pumped discharge; or (c) injected into the soil.

Truck spreaders may be used when dewatered sludge is spread. This semi-solid sludge may be hauled and spread by a conventional box spreader which is ordinarily used to field spread animal wastes. Truck spreaders also are available which allow surface spreading. Direct incorporation into the soil may be accomplished by using a plow, disc, or injection equipment.

Sprinkler irrigation or overland flow irrigation are other possible sludge disposal techniques. These systems for sludge disposal also may be used for tertiary treatment of effluent. With the sprinkler irrigation system, the liquid is sprayed on the land by either a solid-set system or a self-propelled system. Aerosol drift may present problems as more human contact with pathogens is possible. The overland flow system allows sludge to be discharged at the top of a slope and flow to the remaining acreage. A variation of this method, ridge and furrow irrigation, can be used with row crops.

Storage may be part of a landspreading system. It allows more timely applications for sludge to crops but, more importantly, provides an "escape valve" for sludge during the priods when adverse weather prevents landspreading. A lagoon for liquid sludge or a semi-solid storage installation may be located either at the treatment plant or at the landspreading site.

Transportation to the spreading site may be by the spreading vehicle or by separate transportation methods. For example, a large truck could be used to haul dewatered sludge to a spreading site where the sludge would be stockpiled for later application, or a large tank truck could be used to haul liquid sludge to a disposal site where the sludge could be pumped into a spreading vehicle or into temporary storage for later spreading.

Landspreading Costs

There are three main determinants of sludge landspreading costs: type of sludge disposal technology, the distance between the treatment plant and the landspreading site, and the volume of sludge. The following analysis compares costs of sludge disposal by volume of sludge and by disposal technology. Distance to landspreading site is included as an endogenous variable in the analysis. That is, it is assumed that 5 percent of the land in the community is available for landspreading, and each available parcel of land receives 2 dry tons per acre. Thus, the analysis assumes that the amount of sludge determines the distance to spreading sites.

Sludge landspreading costs have been made for five alternative technologies:

a) tank wagon hauling and spreading liquid sludge (5% solids),
b) tank truck hauling and spreading liquid sludge (5% solids),
c) truck spreader hauling and spreading dewatered sludge (25% solids),
d) a separate hauling unit transporting liquid sludge to the spreading site where it is spread by a tank truck (5% solids), and
e) a separate hauling unit transporting dewatered sludge to the spreading site where it is spread by a truck spreader (25% solids).

Assumptions about the values of cost parameters are shown in Table 4. Variable costs are estimated by multiplying the hourly variable cost charges by the time requirement shown in Table 5. Time requirements are a function of hauling a spreading technology. Those technologies spreading liquid sludge are causing substantial volumes of water to be handled. Therefore, those technologies using dewatered sludge have much smaller time requirements per dry ton than the technologies using liquid sludge.

Dewatering costs are included in the cost estimates for those technologies spreading sludge having 25 percent solids content. Vacuum filtration is assumed to be the method used to dewater the sludge. Vacuum filtration requires a high capital outlay and large annual fixed costs. Recent U.S. EPA cost data was used in estimating dewatering costs. These costs are assumed to be a function of treatment plant size. Dewatering costs range from $90 per dry ton for the very small treatment plant to $30 per dry ton for the treatment plant with volumes over 5000 dry tons per year (Anderson).

Using the preceding cost estimation assumptions, the following analysis compares costs per dry ton for the five landspreading technologies over a range of sludge volumes. Figures 1 through 5 plot the costs per dry ton as a function of the amount of sludge spread each year. In Figure 1, costs for relatively small wastewater treatment plants (200 to 1000 dry tons per year) are analyzed. For these treatment plants, the tank wagon and tank truck technologies are clearly preferable. Large per unit fixed costs for technologies using separate hauling units or dewatering make these technologies high cost options.

As sludge volumes become larger (1000 to 3000 dry tons per year), the tank truck technology spreading liquid sludge remains the low cost option (Figure 2). With volumes of 3000 to 5000 dry tons per year (Figure 3), spreading liquid sludge (5 percent solids) remains lower cost than spreading dewatered sludge, but using a separate hauling unit is a low cost option. Between 6000 and 10000 dry tons per year (Figure 4), costs are nearly the same for two technologies--the truck spreader using dewatered sludge and the tank spreader using liquid sludge transported by a separate hauling unit. For large sludge volumes (Figure 5), spreading dewatered sludge and using a separate haul vehicle is the low cost technique.

Conclusions

Landspreading is an economical method of sludge disposal for most communities. Generally, costs of landspreading are lower than costs of other disposal options such as incineration or landfilling.

Landowners may receive substantial benefits from landspreading. Sludge may provide many of the essential nutrients for plant growth. On cropland, benefits of sludge may total $30 per acre if it is applied at low application rates. At the same time, there are some intangible costs to the landowner. The risks associated with pathogens and heavy metals are nearly nonexistent under a well managed landspreading system; nevertheless, these risks are present to some degree for all recipients of sludge. Similarly, recipients of sludge often incur some costs in answering neighbors concerns and/or promoting landspreading in the community. Finally, in our society there is always the risk of legal action being brought against the recipient and the municipality by a third party.

The low cost landspreading technology is largely a function of sludge volume and distance to spreading site. In communities with large amounts of sludge and distant landspreading sites, dewatering sludge to 20 to 30 percent solids results in the lowest cost alternative. For most small and moderate size communities with nearby landspreading sites, spreading liquid sludge is preferred. Temporary storage is suggested for those periods when landspreading is not possible.

Table 1. Costs of Sludge Processing and Disposal, by Disposal Method and Treatment Plant Size

Plant Size		Disposal and Processing Method		
MGD Flow	Sludge Dry Tons Per Year	Vacuum Filter Incinerate, Truck Landfill	Digestion, Truck, Landspread	Digestion, Truck. Landfill
		---$ per dry ton---		
2	540	373	209	347
3	810	293	193	267
5	1350	233	176	213
10	2700	173	147	160
15	4050	147	133	133

Source: Adapted from Shea and Stockton.

Table 2. Comparative Costs for Various Sludge Disposal Processes (1976 Dollars)

Item	Range of Costs (Dollars Per Dry Ton)
Digested sludges:	
Ocean outfall	10 to 35
Liquid landspreading	20 to 54
Digested and dewatered sludges:	
Ocean barging	31 to 44
Landfilling	23 to 53
Landspreading	26 to 96
Dewatered sludges:	
Trenching[1]	116 to 134
Incineration[2]	57 to 93
Heat drying[2]	62 to 115
Composting[1,2]	35 to 50

[1]Costs exclude transporation of sludge to site.

[2]Costs exclude cost of removal of residues and benefits from resource recovery.

Source: Colacicco _et_ _al_. (1977)

Table 3. Potential Value of Nutrients in One Dry Ton of Sewage Sludge[1]

	Percent of Dry Sludge	Value ($/Ton)
Nitrogen[2]	3.3%	$ 8.76
Phosphate (P_2O_5)	5.3	23.32
Potash (K_2O)	0.4	0.80
Total		$32.88

[1]Nutrient price assumptions: Nitrogen, $0.25 per pound; P_2O_5, $0.22 per pound; K_2O, $0.10 per pound.

[2]Nitrogen is assumed to be composed of 67 percent organic nitrogen and 33 percent ammonia nitrogen. This composition varies greatly between waste treatment plants. All ammonia nitrogen is available to the crop while only about 30 percent of the organic nitrogen is available.

Table 4. Cost Assumptions for the Alternative Technologies

Technology[1]	Purchase Price ($)	Annual Fixed Cost[2] ($/Year)	Variable Cost[3] ($/Hour)
a) Tank wagon	42,000	16,800	16.49
b) Tank truck	56,000	22,400	15.47
c) Truck spreader	56,000	22,400	15.47
d) Hauling unit	75,000	30,000	18.88
& tank truck	56,000	22,400	15.47
e) Hauling unit	75,000	30,000	18.88
& tank truck	56,000	22,400	15.47
& loader, etc.	37,500	15,000	16.49

[1] Capacity of the tank wagon is 2,000 gallons and it is pulled by a 100+ horsepower tractor; capacity of the tank truck is 1,600 gallons; capacity of the truck spreader is 7 tons; capacity of the hauling units are 6,000 gallons of liquid sludge and 24 tons of dewatered sludge.

[2] Fixed costs are 40 percent of the purchase price. They include depreciation, interest, insurance, and maintenance.

[3] Variable costs include labor ($6.90 per hour) and fuel ($0.85 per gallon).

Table 5. Time Requirements for Alternative Landspreading Technologies

Technology	Function: Transport (hours/ton/mile)	Function: Load & Unload (hours/ton)
a. Tank wagon	0.268	1.00
b. Tank truck	0.125	0.83
c. Truck spreader	0.025	0.17
d. Hauling unit & tank truck	0.025	0.07 0.83
e. Hauling unit & truck spreader & loader, etc.	0.005	0.03 0.17 0.05

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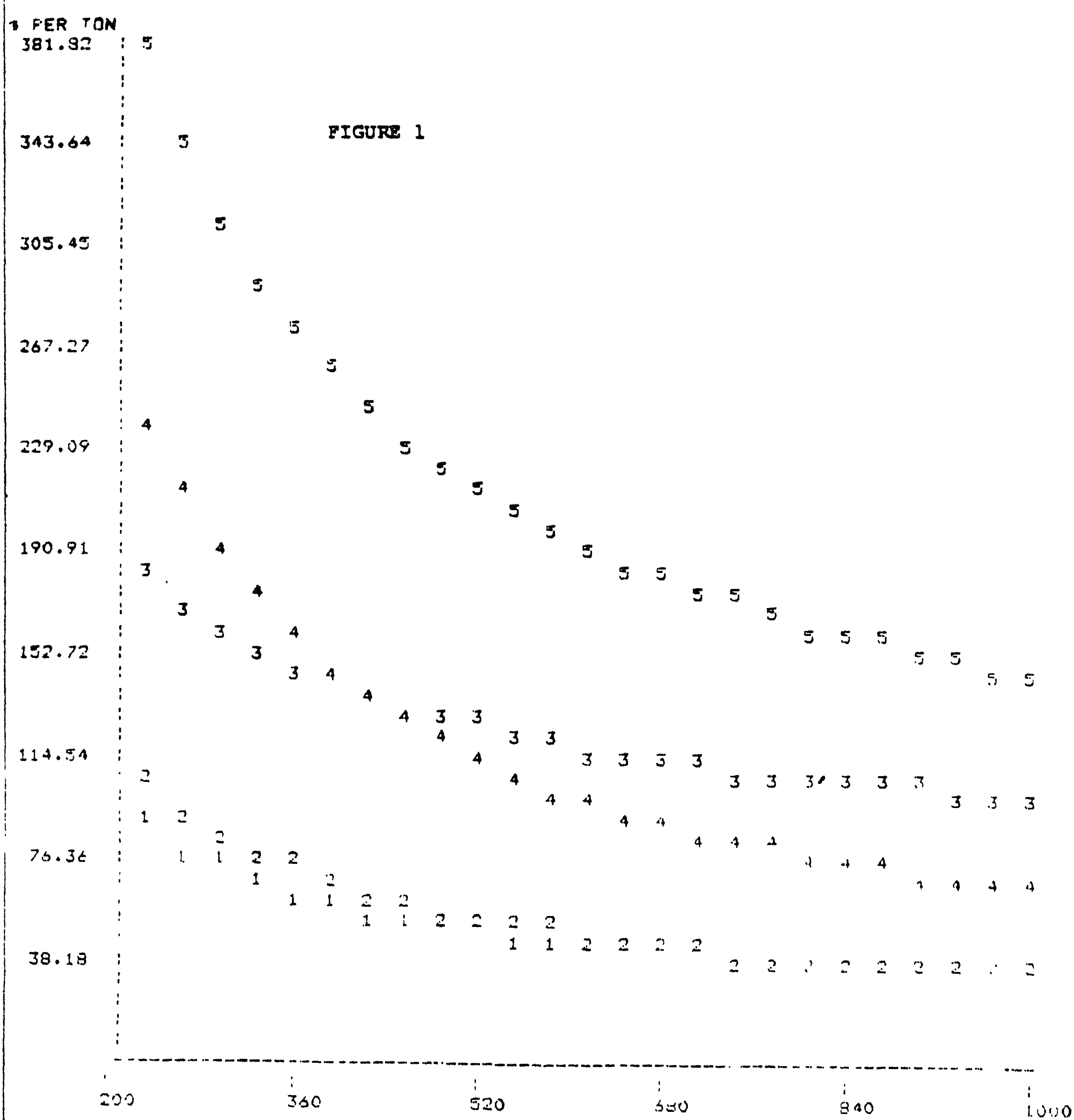
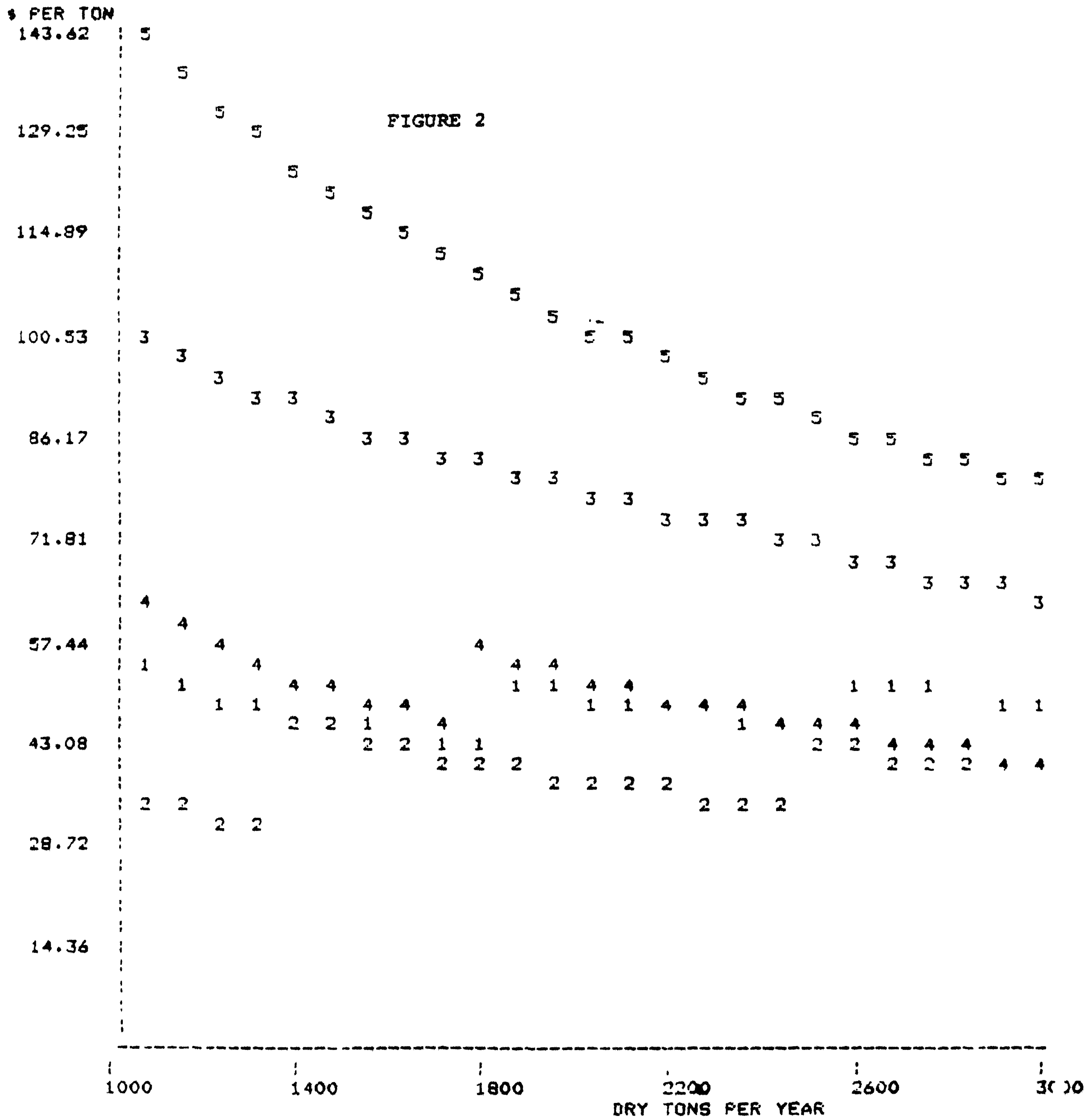


ANNUAL COST PER DRY TON AS A FUNCTION OF THE AMOUNT OF SLUDGE SPREAD EACH YEAR

THE NUMBERS IN THE FIGURE REPRESENT THE FOLLOWING SYSTEMS:
1=TANK WAGON; 2=TANK TRUCK; 3=TRUCK SPREADER;
4=HAULING UNIT + TANK TRUCK; 5=HAULING UNIT + LOADER + TRUCK SPREADER

FIGURE 2



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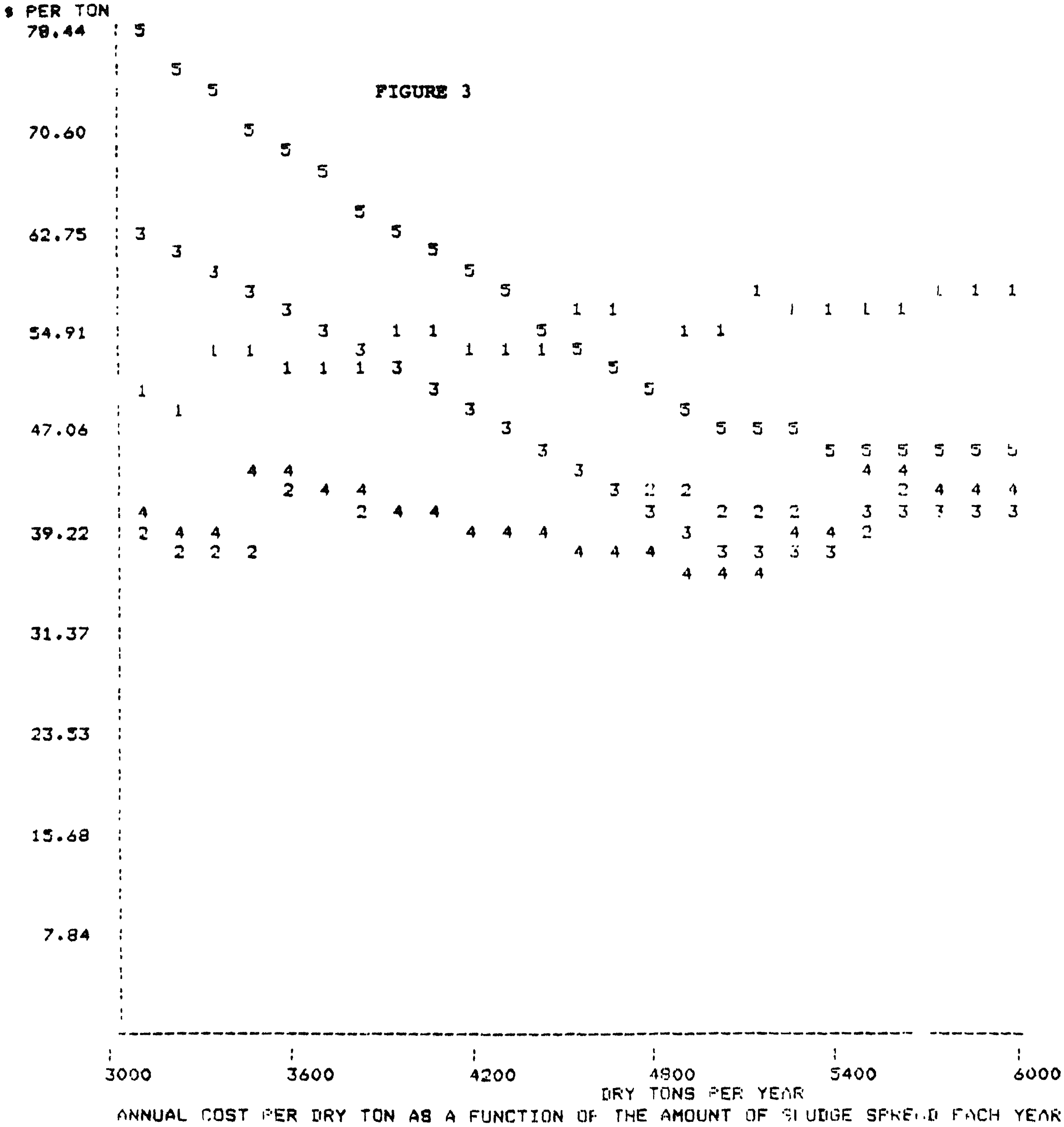

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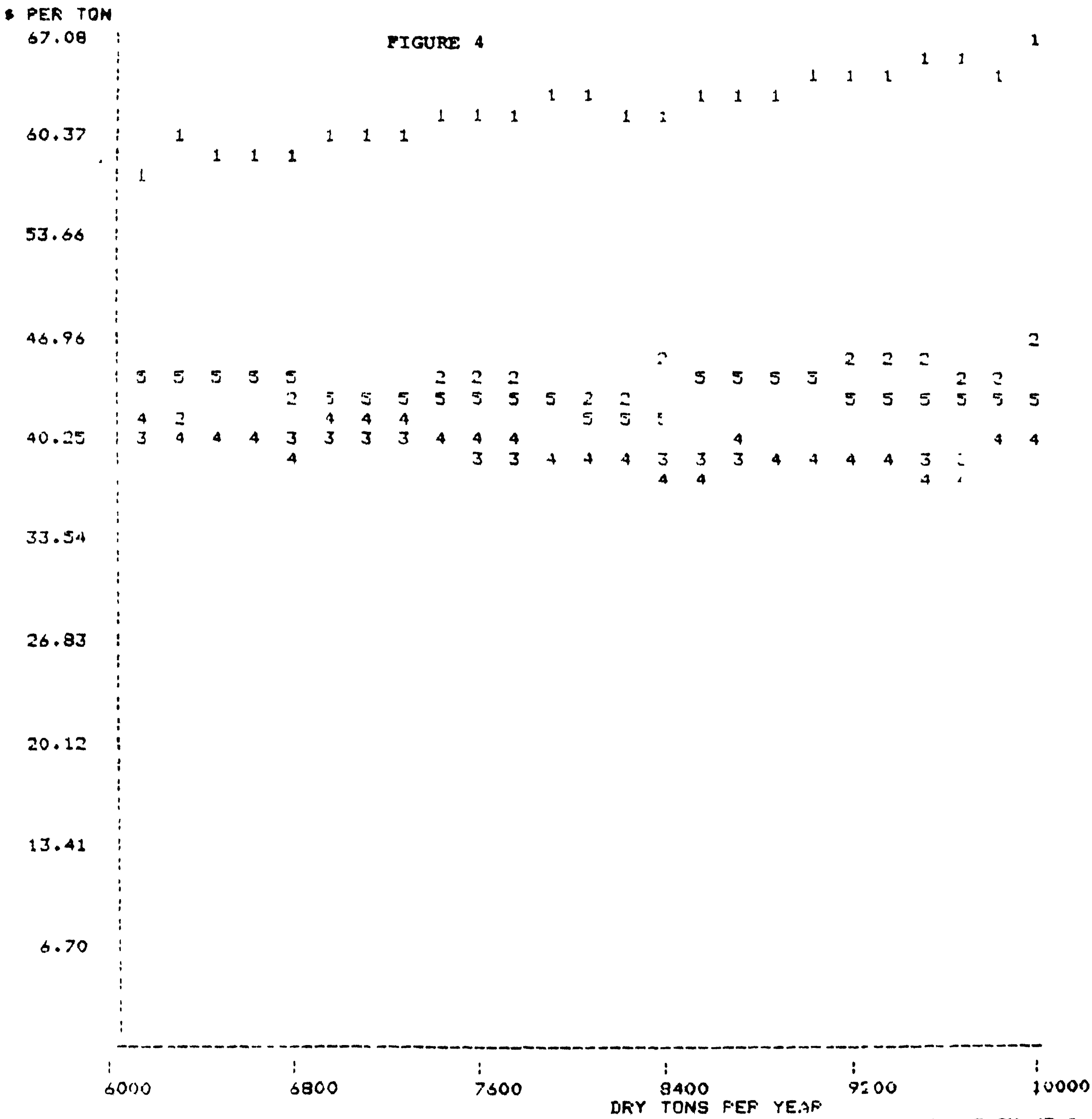

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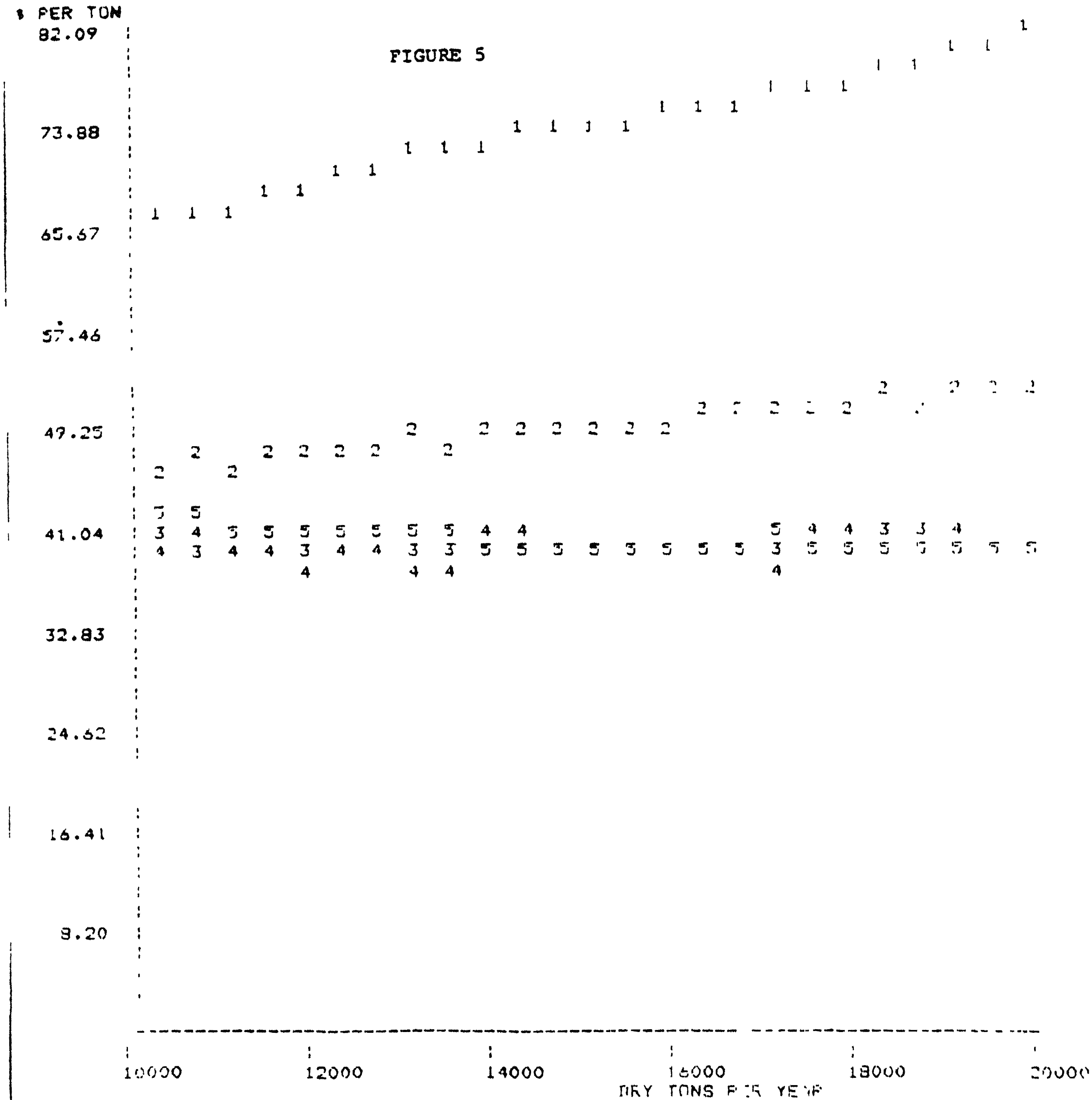

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